ASPECTS OF INTELLIGENT ELECTRONIC DEVICE BASED SWITCHGEAR CONTROL TRAINING MODEL APPLICATION

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Abstract – The design of the protection and control equipment for application in the electrical power sector was object of extensive advance in the last several decades. The modern technologies offer a wide range of multifunctional flexible applications, making the protection and control of facilities more sophisticated. In the same time, the advance of technology imposes the necessity of simulators, training models and tutorial laboratory equipment to be used for adequate training of students and field specialists.

Keywords – IED, switchgear, bay, model, control, training

I. INTRODUCTION

In the last decade the control systems of switchgears, substations and power plant facilities were designed on SCADA based architecture and IED (Intelligent Electronic Devices). The “IED” definition is likely over characterizing the microprocessor multifunctional devices properties, since “artificial intellect” is not implemented, but what can be noted is that modern protection and control equipment requires more intelligent sophisticated preparedness from the side of the personnel. The application specifics of IEDs imposes requirements for high reliability of the devices [2,5,8,9].

II. DESIGN FEATURES

For the purposes of the training of students in the Faculty of Electrical Engineering of TU-Sofia, model based on multifunctional protection and control device (IED) with full size LCD HMI able to display the switchgear single line diagram (SLD) was designed and constructed in collaboration with company working in the area of design, diagnostics and commissioning of electrical power facilities. The model is intended for demonstrations, training of students and collecting statistical data [1,3,4]. The modeled scheme is applicable for single busbar feeder connection of open – air HV switchyard bay or for compact metal clad MV switchgear as well.

The modeled primary scheme represents a feeder bay, equipped with breaker and all typical commutation apparatus. The design of the model may vary from the “industrial design” of MV schemes, as typically combined commutation devices are used there. Elements of the primary scheme in the scope of the model:

- Feeder circuit breaker;
- Disconnectors;
- Earthling switches.

The modeled scheme is presented in Fig. 1. The scheme can be subject of modification – in the IED part functions via the configuration software of the IED. The “hardwire modeled” part – the Bay Local Control Cabinet (BLCC) is realized with physical elements and for functional modifications changes shall be made in the scheme wiring.

III. DESIGN RULES

In the practical “field” situation a commutation device, part of primary scheme – breaker, disconnector can be controlled from 4 locations:

- dispatch center over communication protocols like 60870-5-101 and 60870-5-104;

- substation control room via operator’s SCADA control station, typical “control tool”;

- protection and control panels via HMI of bay control unit (BCU), used typically during commissioning maintenance, etc.;

- bay local control cabinet (BLCC) – the existence of BLCC depends on the particular company requirements. If foreseen – used for local control in emergency cases, maintenance, etc.

- local control buttons on the commutation apparatus control mechanism casing, typically used for testing during commissioning, maintenance.

Another possible level of control is the remote dispatch control applicable for larger and non-manned facilities. For the purposes of the training model at the present state the BLCC and HMI of IED devices levels have been realized.

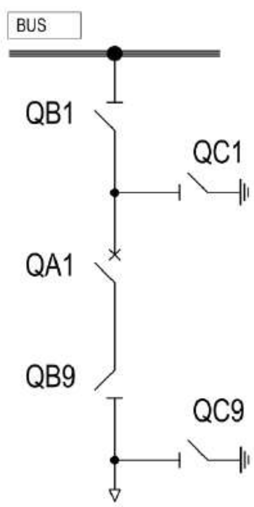

Fig. 1. Primary scheme used for model base.

For the particular case, the model hardware structure has 3 main sections:

- IED based control part (multifunctional device functionality: protection, control, signalization, data acquisition, communication to PC/controller);
- Control panel, simulating the BLCC (command buttons, mode switch, LED position indicators);
- Breaker model and accessories (auxiliary relays, time relays and elements to simulate the breaker and other commutation devices drive mechanisms and their auxiliary block-contacts).

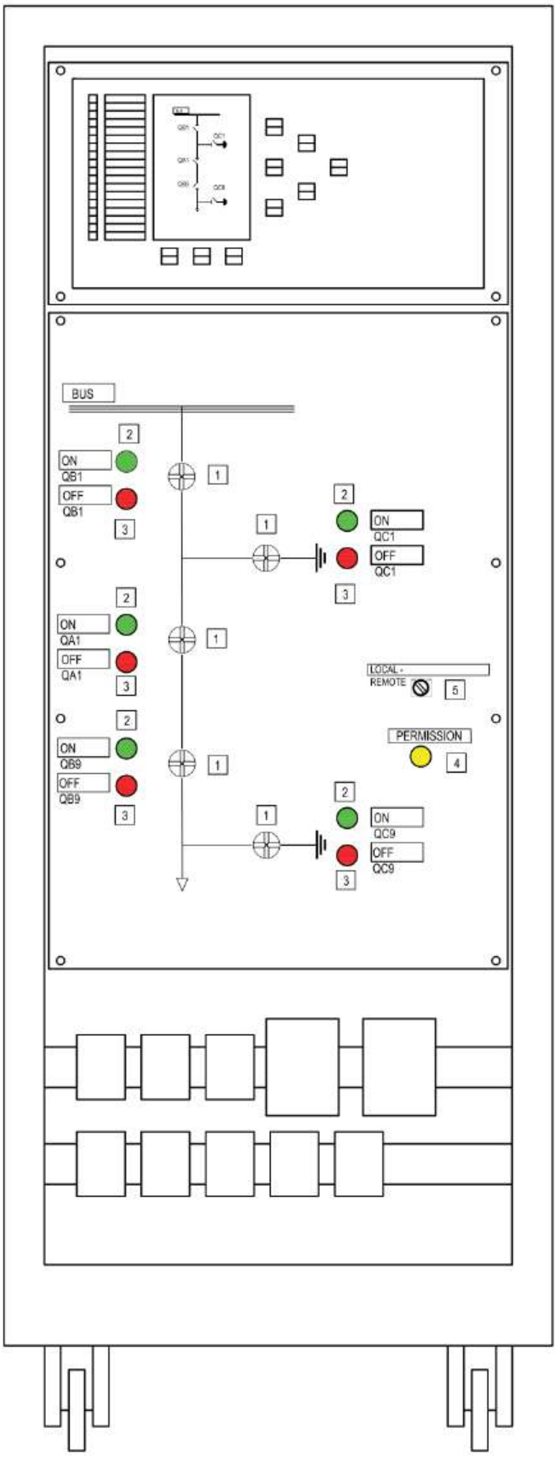

Fig. 2. Model front panel design.

The model front panel design is presented in Fig. 2.

The arrangement of all components was designed in one 19” rack cabinet with access to all the components from the front and rear side. The logic has been hard-wired between the IED, control panel and auxiliary elements.

At next stage it is foreseen the BLCC simulating control panel to be reconfigured as detachable unit, remotely located with integrated controller and fiber – optic connection to IED. The currently constructed functional specifics and the future extensions of the technical solution in limited extent may deviate from the “industrial applications”, but the designed structure was targeted to provide mostly access points for students and options to simulate secondary circuit failures, to test Breaker Failure Protection (BFP), autorecloser function, etc.

The BLCC was fitted with additional push button for “permission”. The permission button shall be kept pressed simultaneously with the respective command button (Close / Open) in order to make the intended commutation operation possible. The functionality was foreseen to avoid erroneous commands by inadvertent button actuation.

The functional scheme (the logical scheme) of the model is presented in Fig. 3.

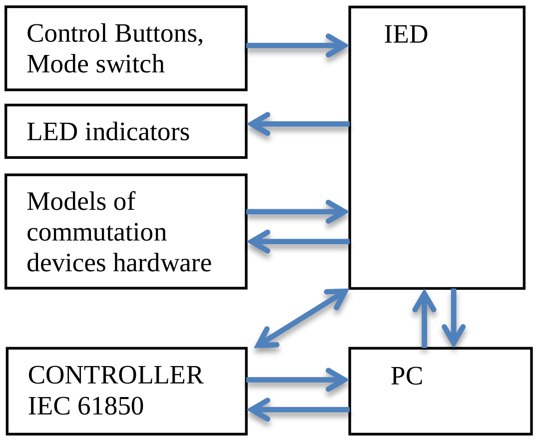

Fig. 3. Model front panel design.

The typical tasks which the students must accomplish, performing laboratory practices:

- Check the operation functionality of the model, interlocks test between the commutation devices;
- Test of the commutation devices permitted switching sequence: circuit breaker, disconnectors and earthing switches. The typical sequence is taking the breaker bay into “safe” position with all pertaining disconnectors opened and respective grounding switches closed (or reconnection of the feeder to the bus);
- Test of the commutation sequence of grounding switches – check of the possibility for incorrect grounding of live parts;
- Transfer of control mode via the Local / Remote switch on the BLCC panel;
- Verify the configuration of the BCU IED – matrix of signals, etc.;
- Test of protection functions;

- Test of BFP function – option to change the “breaker response time” with modification of the time relay, used for breaker operation modeling;
- Overall IEC61850 messages (GOOSE messages) readings with the respective signals verifications;
- Configuration and testing the communication to the dispatch center (virtual);
- Learning the structure and the possibilities of different communication protocols.

The model allows “errors”/”faults” to be simulated with the IED firmware settings changes and/or wiring changes in the hardware part.

The collected information for “personnel response” can be statistically analyzed in different aspects. The response of the “operator” can be estimated in respect to:

- Time to perform successfully a commutation sequence;
- Time to respond to fault conditions (simulated with IED testing device to trigger protection function);
- Time to perform successfully a modification in software / detect and clear a mistake in configuration;
- Time to download records from IED.

In order to estimate ambient conditions impact on the personnel response, the following variants are possible:

- Ambient light variation / low level of lighting;
- Presence of noise source in the surrounding area (alarm siren);
- Presence of other personnel in the vicinity of IED HMI, BLCC.

The performed experiments were organized as a set of switching sequences, accomplished by group of students.

Table 1 presents data for the experiment operation of the model for several cases of ambient conditions.

One series of operations was performed in normal conditions (without “disturbances” for the operator) and the other three series were made with presence of disturbance factors.

Table 1

Disturb factor	**-**	**Light**	**Sound**	**Attend.**
Percent:	**n of total %**	**n of total %**	**n of total %**	**n of total %**
Expected Norm t	43	29	39	32
Norm t +05%	18	25	18	21
Norm t +10%	11	14	14	14
Norm t +15%	7	11	14	7
Norm t +20%	11	18	7	11
Norm t +25%	7	0	4	7
Norm t +30%	4	4	4	7

The expected time for correct accomplishment of the task was assumed as sum of the operator’s switching actions plus the “own time” of the respective devices (commutation apparatus).

$$t_{SO} = t_{OA} + t_{DM} \qquad (1)$$

where t_{SO} – time for switching operations

t_{OA} – time for operator’s actions

t_{DM} - time for drive mechanism of the commutation devices (operator independent, design characteristic)

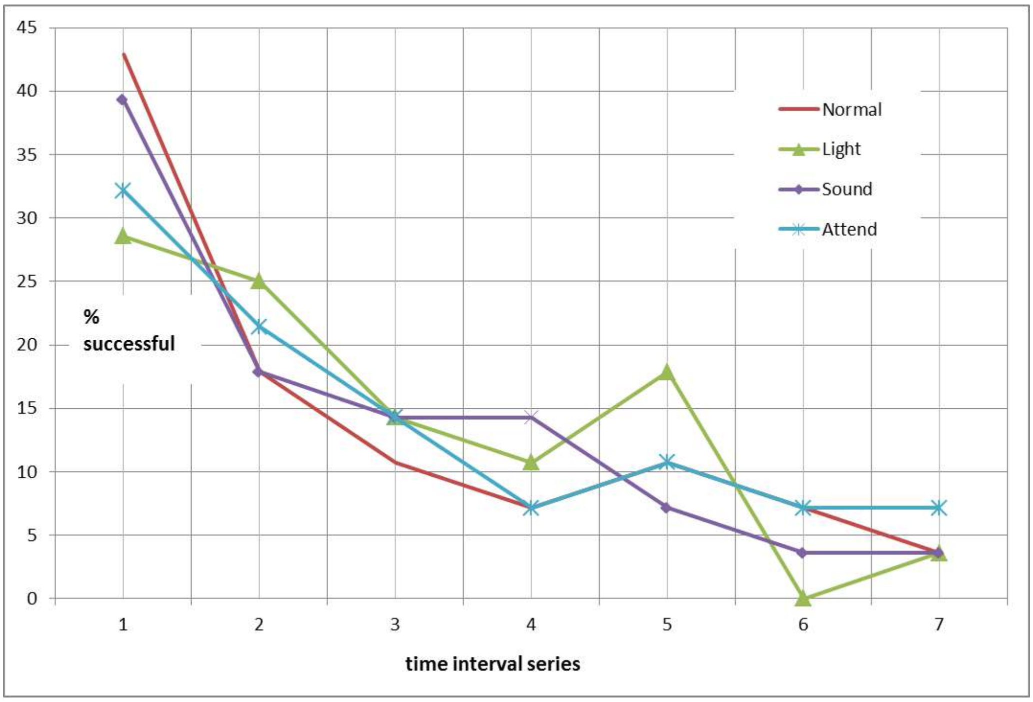

Fig. 4. Graphic representation of model experimental operation results.

The time for operator's actions can be regarded as sum of the time for accomplishment of the task in normal conditions plus additional time delay caused by the respective disturbance:

$$t_{OA} = t_{OA\,norm} + t_{OA\,ad} \quad (2)$$

where t_{OAnorm} – time for switching operations in normal conditions (without disturbance),

$t_{OA\,ad}$ – additional time imposed by disturbing factor

The sensitivity of the "successful mission time" in respect of the interfering factors can be calculated as:

$$S_{TOA} = \frac{t_{OA} - t_{OAnorm}}{t_{OAnorm}} \quad (3)$$

In case of combination of disturbances, the importance of the different impacts on operator's response, can be weighted and combined in common expressions for estimation of the response time.

$$t_{OA} = \sum_{i}^{n} C_{DFi} \,.\, t_{OAnorm} \quad (4)$$

where C_{DFi} – coefficient of importance for the impact of disturbing factor "i" (for the case i = 3).

Preliminary experiments of combined ambient area disturbances indicate, such "combined impact" situation may lead not only to delay in correct response, but to incapability of finalizing successfully a task.

The conditional probabilities of task successful accomplishment can be defined, if the probability for occurrence of interfering factors is known. Such conditional probabilities can be used for prognosis of "failure" or "success" scenarios for particular conditions.

For correct estimation of the results related to operation of real control panel – for instance BCU in HV switchgear, the probabilities of interfering conditions shall be precisely identified, whether they can occur simultaneously and if there are mutual dependences. Incorrect assumption of independent or mutual excluding factors may distort the probabilistic assessment results.

IV. CONCLUSIONS

The performed experiments with the model, operated by students proved that it can be used for training purposes and in the same time to collect statistical data for the response of operators, impact of ambient conditions on operator's actions and demonstration of IEC61850 based communication. The procedures for statistical data processing are under development and will target obtaining qualitative and quantitative indices for dependence of the "human factor" in control of equipment in respect of the site conditions [6,7,10,11].

The performed tests indicated that for the particular case the ambient light caused more significant effect on the "operator's response", compared with other disturbance factors. For the particular model – it can be explained with the design specifics: the position indicators are illuminated, but the labeling is "passive" – no back light.

The model in combination with experiments related to ambient work conditions can be used for improvement of control panel's ergonomic design and in the same time to evaluate the impact of the operator working conditions on the probability for successful accomplishment of task [12].

The dependences of the facility operability in respect of ambient conditions levels (values) can help finding optimal design towards working environment. The applicable regulations for ergonomic design and safety shall also be taken into account for particular design final decisions.

Further extension of the model is foreseen for creating a second BCU model for different bus configuration and link to larger existing switchgear model [12].

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